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Comparison of two different bioenergy production options from late harvested biomass of Estonian semi-natural grasslands

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ABSTRACT

Semi-natural grasslands are characterized by high biodiversity and can be maintained only with continuous management. In current situation, without sufficient demand for these biomass as cattle fodder, this source can be used for bioenergy production. In Estonia the largest average annual dry biomass yield per area was achieved in alluvial meadows (5.5 t ha^{-1}) and the lowest in wooded meadows (1.9 t ha^{-1}). Chemical characteristics of herbaceous biomass from wooded meadows differed from mesic and alluvial meadows resulting in the highest values of N, Ca, K, Mg and ash (1.3%, 2.4%, 0.3%, 10.9% and 9.5% of the dry matter, respectively) and lower ash softening temperature (1161 °C). The energy potential for combustion was estimated to be 102, 53 and 34 GJ ha^{-1} y^{-1} for alluvial, mesic and wooded meadows, respectively. The highest feedstock-specific methane yield can be produced from the biomass of wooded meadows (299 l_N CH_4 kg^{-1} VS (volatile solids)) and the lowest from alluvial meadows (269 l_N CH_4 kg^{-1} VS). The area-specific methane yield was obtained from 514 for wooded to 1375 m^3 CH_4 ha^{-1} for alluvial meadows that corresponds to 20 and 55 GJ ha^{-1}. Via biogas production it is possible to achieve less than 60% of energy available for combustion.

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1. Introduction

Semi-natural grasslands have been formed and shaped by extensive human activities, mainly grazing and mowing. In Europe these plant communities are often the ecosystems with the highest biodiversity on both micro and wider landscape level (e.g. Ref. [1]). Many types of these grasslands are listed in Annex I of the EU Habitat Directive [2] as habitats to be protected by creating Natura 2000 areas where seeding, fertilisation or alteration of mowing period is unfavoured. It is important that semi-natural grasslands are managed continuously with extensive methods as plant species richness is negatively related to land use intensification [3]. Fertilization increases productivity per area but decreases also species diversity [4].

Throughout Europe the area of semi-natural grasslands has decreased considerably during the last century [1]. In Estonia this area decreased to almost one-fifth of its original cover, from 1,571,000 ha in 1939 to 303,000 ha in 1981 [5]. In 2006 semi-natural grasslands were estimated to cover 130,000 ha in Estonia [6]. Active nature conservation policy in the EU and current subsidy systems has promoted the expansion of the area covered semi-natural habitat types [7]. Currently management of about 25,000 ha of semi-natural grasslands is subsidised in Estonia [8]. According to the Nature Conservation Agenda [9] the target for 2020 is 45,000 ha. However, like many countries, Estonia is also facing great difficulties with consuming of herbage from these grasslands. For instance, it is estimated that approximately 25% of all German grasslands will be abandoned in the next future because of the high harvesting costs and low forage value (e.g. Ref. [10]).

Recently much attention has been paid to bioenergy production from agricultural sources. The European Commission has set the goal of raising the proportion of energy consumption from renewable energy to 20% by 2020 [11]. Estonia is obliged to increase the share of renewable energy sources up to 25% of total energy consumption and the share of biofuels up to 10% of transport fuels for 2020 [12]. According to Estonian National Renewable Energy Action Plan [12] the target for bioenergy from biogas is 0.5 PJ for 2020, but in 2011 it was only 115 TJ [13]. It is based primarily on landfill gas and used mainly for heat and power production. Further activities for producing biogas from different agricultural substrates can be expected. However, the common practice of growing dedicated energy crops for bioenergy purposes

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may be crucial for food production for a finite land resource [14]. Non-food cropping from marginal lands [15] as well as additional bioenergy raw material from semi-natural grasslands diminishes this problem. Therefore alternative usage of biomass from semi-natural grasslands has become a challenging option for bioenergy production. It has been widely demonstrated that regular biomass harvesting from semi-natural grasslands is obligatory to maintain their biodiversity [16–18]. Moreover, removal of harvested biomass from these grasslands is essential in order to preserve the original soil characteristic [19,20]. On the other hand, the potential of biomass from semi-natural grasslands depends on local conditions. For instance, Steubing et al. [21] assumed that grass from extensive meadows and mountain pastures in Switzerland does have only limited bioenergy potential. On the other hand, it has been demonstrated that high-diversity grasslands can provide reasonable amount of energy in the USA [22]. In boreal climate conditions the energy output from semi-natural grasslands' biomass is comparable with the energy profit from the local favourite herbaceous bioenergy crop (*Phalaris arundinacea*) [23]. Moreover, there are also results available that the energy output of low-input high-diversity grasslands' biomass on degraded soil is nearly equal to that of ethanol from conventional corn grain on fertile soil in China [24].

Like any other biomass, the biomass from grasslands can be converted to bioenergy by different options [25]. Herbaceous biomass may be used as solid biofuel for combustion and be feasible feedstock for biogas production [26,27]. The combustion of biomass from semi-natural grasslands can be affected by technical constraints due to high concentration of minerals, nitrogen and sulphur leading to problems with ash melting, boiler corrosion or increased fume emissions [28,29]. In semi-natural grasslands, the mowing period is usually restricted by nature conservation requirements starting in Estonia from July 10. The late cutting period can lead to lower biogas production potential [30]. In general, for anaerobic biogas digestion high content of easily biodegradable compounds and certain amount of different nutrients in biomass are favoured [31–34]. Biodegradation of lignocellulosic feedstock under anaerobic conditions is difficult to achieve and leads to lower feedstock biogas yield [31]. These crucial characteristics may vary between plant species, grassland types and harvesting time [27]. For instance, nitrogen or crude protein content of hay from semi-natural grasslands decreases during the growing season [35,36]. To improve biodegradability and to enhance methane production from herbaceous biomass attractive and promising pretreatment methods have been worked out [10,37,38]. Methane production potential of different energy crops and grasslands with different management regimes have been studied in Europe [30,39–41], but there is only a limited knowledge about the methane production potential of late harvested herbaceous biomass from semi-natural grasslands that are valuable for nature conservation purposes in boreal zone.

The aim of our study was to assess the energy potential of herbaceous biomass originating from different semi-natural grassland types with one late harvest, without seeding and fertilising. For this purpose we estimated the biomass production of different semi-natural grassland types in Estonia, that were considered to be the most available (mesic meadows), the most nutrient-rich (alluvial meadows) or having the largest biodiversity (wooded meadows). In order to evaluate the suitability of different options for bioenergy production we compared the feedstock-specific methane yield with calorific value of the biomass and analysed the amount of the most crucial elements in biomass. To enable further estimations of energy input needed for bioenergy production, we studied also the feedstock-specific methane yield dynamics during experiment.

2. Materials and methods

2.1. Location and weather conditions in the study area

The study was carried out on the Estonian mainland, located on the north eastern shore of the Baltic Sea between 57.3° and 59.5°N and 21.5° and 28.1°E. According to the Estonian Meteorological and Hydrological Institute [42] the climate in the region is temperate continental with annual average temperature 5.6 °C and precipitation 646 mm.

2.2. Site selection

The fieldwork was carried out in the first half of July that is the typical mowing time according to local Natura 2000 management rules (mowing period is starting from 10th of July) in 2007 and 2010. Fieldwork was performed in different semi-natural grassland types: alluvial meadows (NATURA 2000 habitat type Northern boreal alluvial meadows code 6450), mesic meadows (NATURA 2000 habitat type Fennoscandian lowland species-rich dry to mesic grasslands code 6270) and wooded meadows (NATURA 2000 habitat type Fennoscandian wooded meadows code 6530).

2.3. Biomass estimation

For the biomass yield studies in 2007 nine alluvial, six mesic and four wooded meadows were selected and biomass samples from nine round plots of 0.07 m^2 per study site were taken. Plots were located along a transect and distance between the plots was at least 30 m. The aboveground biomass of plants rooted inside the circle was harvested with scissors above the ground level. Samples were weighed to determine fresh weight. Five samples from each studied meadow were dried for 48 h at 80 °C to determine dry weight.

2.4. Biomass chemical analyses

The mixture of the dried biomass per meadow was taken immediately after collecting to the Laboratory of Plant Biochemistry of the Estonian University of Life Science to measure its NDF (neutral detergent fibre) and ash content. From critical chemical elements we analysed the concentrations of nitrogen (N), calcium (Ca), magnesium (Mg), and potassium (K). Analyses of the organic compounds, K and ash were carried out according to standardised methods [43]. For Kjeldahl Digest determination of Ca, and Titan Yellow method determination of Mg, a Fiastar 5000 was used (AN 5260 and ASTN90/92, respectively). Total protein value was calculated by multiplying total N value by factor of 6.25 [44]. CV (gross calorific value) was measured with an IKA WERKE Calorimeter System C 5000 in the laboratory of the Department of Forest Industry of the same University. The calculations of AST (ash softening temperature) were based on the concentrations of K, Ca and Mg according to Hartmann [45].

2.5. Biochemical methane potential

In 2010 we collected a mixed biomass sample from two meadows per each grassland type and dried it in oven 60 °C. This biomass was used for biochemical methane potential experiment in batch experiments with three replicates in the Laboratory of Bio- and Environmental Chemistry in Estonian University of Life Science. The test was based on a modified version of the guidelines for biochemical methane potential estimation by Owen et al. [46]. DM (dry matter) and VS (volatile solids) were determined according to standardised method by drying the biomass and inoculum at 105 °C for overnight and incineration at 525 °C for 2 h.

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